AMS ^{14}C DATING OF HISTORIC ERUPTIONS OF THE KIRISHIMA, SAKURAJIMA AND KAIMONDAKE VOLCANOES, SOUTHERN KYUSHU, JAPAN

MITSURU OKUNO,[1] *TOSHIO NAKAMURA*[2] *and TETSUO KOBAYASHI*[3]

ABSTRACT. In the historic period, several large eruptions were recorded from Kirishima, Sakurajima and Kaimondake volcanoes in southern Kyushu, Japan. Estimated dates of volcanic activity were established on these volcanoes through historical documentation of major eruption events. This study presents the correspondence between these documents and the records of AMS ^{14}C dating of soils underlying tephra layers. We conclude that AMS ^{14}C dates of soil materials can be useful in correlating tephra layers with documentary records of eruption.

INTRODUCTION

Reliable radiocarbon dates can be obtained from the analysis of soil layers buried by alluvial and flood deposits (Orlova and Panychev 1993), because these deposits accumulate very quickly and prevent any penetration by rootlets from recent vegetation. Soil samples are easily and systematically available for ^{14}C dating of volcanic eruptions (Braitseva *et al.* 1993). Okuno *et al.* (1997) showed that the ^{14}C date of soil just below a tephra layer represents an eruption age.

The purpose of this study is to determine more precisely the effectiveness of soil ^{14}C dating in estimating eruption ages by comparing it with the documentary records of actual eruptions. In the historic period, several tephra layers originated from the eruptions of Kirishima, Sakurajima and Kaimondake volcanoes, located from north to south in the Kagoshima graben, southern Kyushu, Japan (Fig. 1). Recently, Kuwahata and Higashi (1997) summarized the stratigraphic relation between prominent tephra layers and archaeological remains such as pottery fragments excavated from various archaeological sites in southern Kyushu.

We here present the results of accelerator mass spectrometry (AMS) ^{14}C dating as useful guides in determining the historic eruptions of Kirishima, Sakurajima and Kaimondake volcanoes.

OUTLINE OF HISTORIC ERUPTIONS OF KIRISHIMA, SAKURAJIMA AND KAIMONDAKE VOLCANOES

Kirishima is a collective name given to a group of more than 20 small volcanoes (Imura 1994). Since AD 742, more than 60 eruptions have been documented; historic eruptions have occurred mainly at Ohachi and Shinmoedake volcanoes (Fig. 2). At the eastern foot of Kirishima, three prominent tephra layers are observed (Fig. 2); they are, in descending order, Shinmoedake-Kyoho Pumice (Sm-KP), Ohachi-Takaharu Scoria (Oh-ThS), and Ohachi-Katazoe Scoria (Oh-KzS). The second and third tephras have been considered to correspond to documentary records in AD 1716–1717 and AD 788, respectively (*e.g.*, Inoue 1988; Imura and Koga 1992). However, pottery fragments of the late 9th century were found in the soil layer below the Oh-ThS at the Hirohara-chiku archaeological site (Kuwahata and Higashi 1997), suggesting that the previously estimated age of Oh-ThS is inaccurate.

Sakurajima is a post-caldera volcano situated on the southern rim of Aira caldera (Fig. 1). It consists of two adjoining stratocones, the Kitadake and the overlying Minamidake, and several parasitic cones (Fukuyama 1978; Kobayashi 1982). Major eruptions were documented in AD 764 (Tenpyo-

[1]JSPS Research Fellow, Nagoya University, Nagoya 464-8602 Japan. Present address: Department of Earth System Science, Fukuoka University, Fukuoka 814-0180, Japan
[2]Dating and Materials Research Center, Nagoya University, Nagoya 464-8602 Japan
[3]Department of Earth and Environmental Sciences, Kagoshima University, Kagoshima 890-0065 Japan

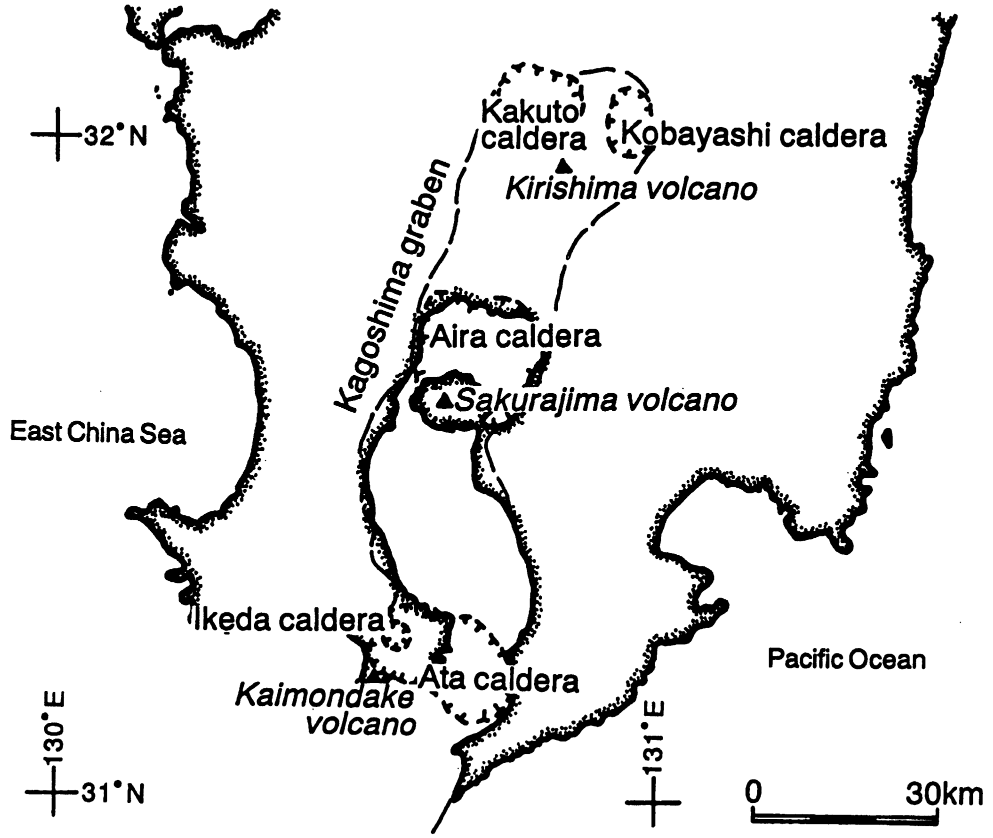

Fig. 1. Location map of Kirishima, Sakurajima and Kaimondake volcanoes

houji era), AD 1471–1476 (Bunmei era), AD 1779 (An-ei era) and AD 1914 (Taisho era). Figure 3 shows the stratigraphic relations of these four tephra layers from Sakurajima volcano. These tephras (in ascending order: Sz-Tn, Sz-Bm, Sz-An and Sz-Ts) consist mainly of whitish pumice and ash. Ten ^{14}C dates for the first three tephras were obtained by Okuno *et al.* (1997).

Kaimondake is a composite volcano consisting of a basal stratovolcano and a central lava dome (Nakamura 1967; Fujino and Kobayashi 1997). Two large eruptions were recorded from this volcano, one in AD 874 (Jogan era) and the other in AD 885 (Nin-na era). Figure 4 shows the columnar section of tephra layers originating from these two historic eruptions. Naruo, Nagayama and Shimoyama (1997) discussed the reliability of historical documents in light of tephrastratigraphy and archaeology.

Methods

Eleven soil samples underlying a tephra layer by 0–2 cm were collected for ^{14}C dating. The nondisturbance of the soil layer was checked by a careful observation of the boundary between the soil and tephra layers (Okuno *et al.* 1997). Three charcoal samples within the tephra layers were also collected.

https://doi.org/10.1017/S0033822200018786 Published online by Cambridge University Press

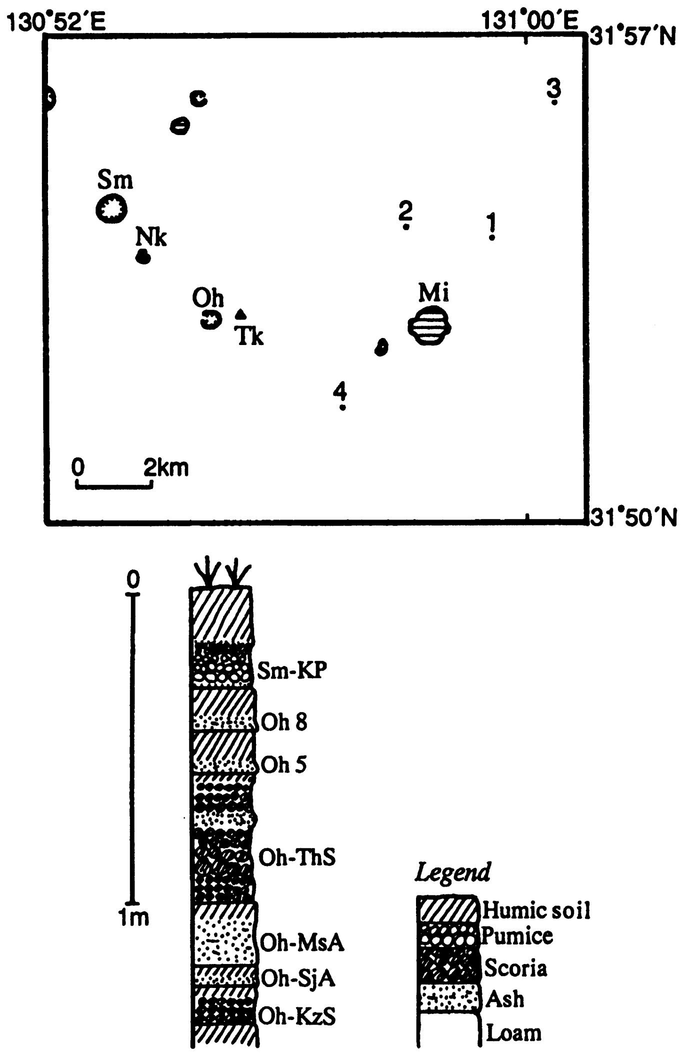

Fig. 2. Sample locations and columnar section of tephra layers from Kirishima volcano at Loc. 1. Sm = Shinmoedake; Nk = Nakadake; Oh = Ohachi; Tk = Takachihonomine; Mi = Miike

Sample preparation procedures were as described by Okuno *et al.* (1997). A humin fraction of the soil samples was supplied for AMS ^{14}C dating. Charcoal fragments, after ultrasonic washing, were also purified by a routine acid-alkali-acid (A-A-A) treatment to remove contamination completely. The pretreated samples were sealed in an evacuated Vycor® tube with CuO, and combusted at 950°C. The resulting CO_2 was purified cryogenically in a vacuum line and then reduced catalytically to graphite on Fe-powder with hydrogen gas in a sealed Vycor tube (Kitagawa *et al.* 1993). The $^{14}C/^{13}C$ ratios of the graphite targets were measured along with the standards (NBS oxalic acid, SRM-4990) using a Tandetron accelerator mass spectrometer at the Dating and Materials Research Center, Nagoya University (Nakamura *et al.* 1985; Nakamura, Nakai and Ohishi 1987). The carbon isotopic fractionation was corrected by using the sample $^{13}C/^{12}C$ ratio ($\delta^{13}C_{PDB}$) measured for an aliquot of CO_2 gas with a Finnigan MAT™ 252 mass spectrometer.

https://doi.org/10.1017/S0033822200018786 Published online by Cambridge University Press

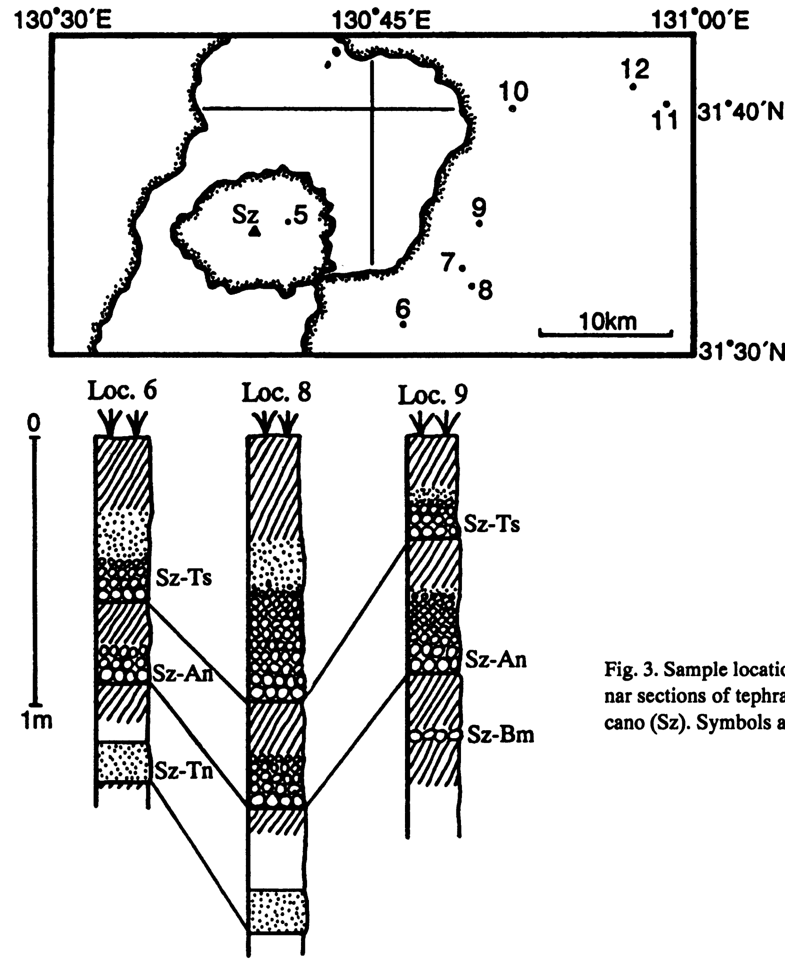

Fig. 3. Sample locations and representative columnar sections of tephra layers from Sakurajima volcano (Sz). Symbols as in Fig. 2.

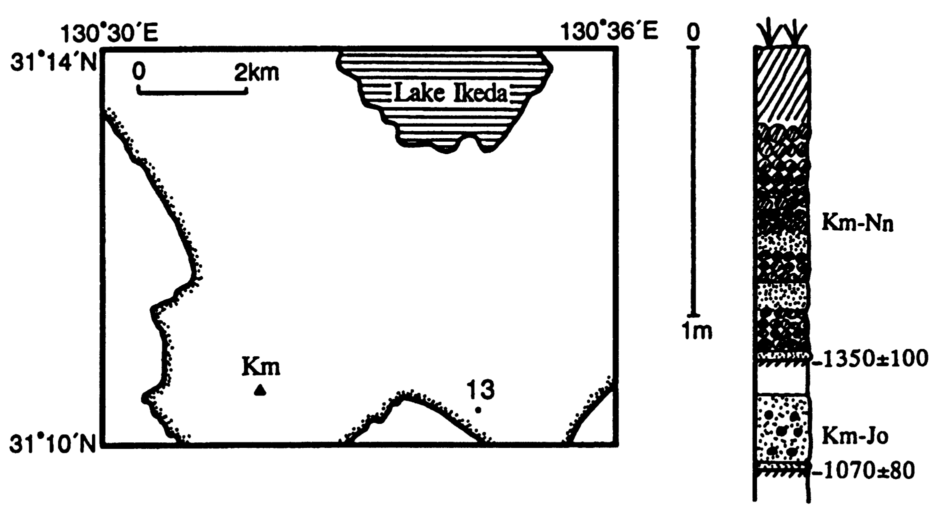

Fig. 4. Columnar section and AMS ^{14}C dates of tephra layers from Kaimondake volcano (Km) at Loc. 13. Symbols as in Fig. 2.

https://doi.org/10.1017/S0033822200018786 Published online by Cambridge University Press

RESULTS AND DISCUSSION

Table 1 shows the 25 AMS ^{14}C dates that correspond to 5 charcoal and 20 soil samples. NUTA-4240 and 4265 were obtained from the same charcoal fragment. The ^{14}C dates are calibrated to calendar years based on dendrochronological data (Stuiver and Pearson 1993) using the Calib ETH 1.5b program (Niklaus *et al.* 1992).

Figure 5 shows the ^{14}C dates plotted against various tephras from Kirishima volcano and these dates are found to be almost consistent with tephrastratigraphy. For Oh-ThS, five ^{14}C dates all lie within a two-sigma uncertainty range (Fig. 5), and all the calibrated year ranges (Table 1) are considerably younger than AD 788, which was previously assigned to Oh-ThS. The ^{14}C dates obtained are also consistent with the pottery chronology. Based on our calibrations as well as documentary records, we consider that Oh-ThS and Oh-KzS were formed in AD 1235 and AD 788, respectively.

Figure 6 shows the ^{14}C dates plotted against various tephras from Sakurajima volcano. No overlapping of dates has been observed from each group; however, ^{14}C dates of soil samples just below the Sz-Bm tephra are found to be systematically older than the calendar age by a few hundred years or more. These abnormalities may be due to the contamination of the underlying soil layer. In general, we may conclude that these dates are consistent with the calendar age and that the Sz-Tn eruption occurred in AD 764, as earlier suggested by Okuno *et al.* (1997).

Only two ^{14}C dates were obtained from Kaimondake volcano and they showed two different calibrated ranges (Table 1). For the Km-Jo tephra from the AD 874 eruption, the calibrated range (cal AD 881–1039) is almost consistent with its historical date; however, the Km-Nn tephra from the AD 885

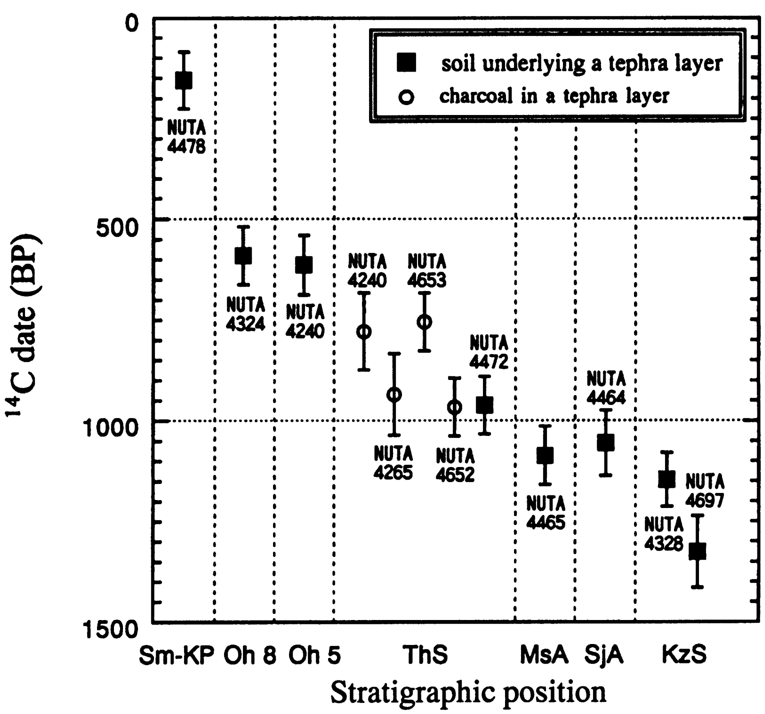

Fig. 5. Relationship between stratigraphic position and AMS ^{14}C date in Kirishima volcano. The error bars represent 1σ uncertainties.

https://doi.org/10.1017/S0033822200018786 Published online by Cambridge University Press

TABLE 1. AMS ^{14}C Dates of Eruptions of Kirishima, Sakurajima and Kaimondake Volcanoes

Lab. No. (NUTA-)	Loc.*	Stratigraphic position	Material	δ^{13}C (‰)	^{14}C age (yr BP)	Cal range AD, probability (%)	Ref.†
Kirishima Volcano							
4478	1	Below Sm-KP	Soil	−23.9	150 ± 70	1674–1707 (17.8)	
						1713–1778 (35.1)	
						1797–1821 (13.2)	
						1837–1875 (19.1)	
						1914–1941 (14.9)	
4324	1	Below Oh 8	Soil	−25.1	590 ± 70	1306–1363 (61.6)	
						1376–1412 (38.4)	
4473	1	Below Oh 5	Soil	−20.0	610 ± 70	1305–1367 (68.9)	
						1373–1401 (31.1)	
4240	2	In Oh-ThS (mid)	Charcoal	−11.4	780 ± 100	1070–1070 (0.3)	
						1129–1131 (0.9)	
						1160–1307 (92.9)	
						1361–1378 (38.4)	
4265	2	In Oh-ThS (mid)	Charcoal	−11.4	930 ± 100	1022–1205 (100)	
4653	3	In Oh-ThS (mid)	Charcoal	−26.0	750 ± 70	1213–1306 (94.2)	
						1364–1375 (5.8)	
4652	3	In Oh-ThS (low)	Charcoal	−28.0	970 ± 70	1017–1161 (100)	
4472	1	Below Oh-ThS	Soil	−24.8	960 ± 70	1020–1161 (100)	
4465	1	Below Oh-MsA	Soil	−24.6	1090 ± 70	889–1018 (100)	
4464	1	Below Oh-SjA	Soil	−24.2	1060 ± 80	887–1044 (94.6)	
						1104–1113 (3.4)	
						1147–1151 (2.0)	
4328	1	Below Oh-KzS	Soil	−24.8	1150 ± 70	820–842 (11.9)	
						858–984 (88.1)	
4697	4	Below Oh-KzS	Soil	−24.8	1330 ± 90	639–791 (93.9)	
						794–810 (6.1)	
Sakurajima Volcano							
4072	8	Below Sz-An	Soil	−17.4	200 ± 70	1647–1703 (28.2)	†
						1717–1819 (55.1)	
						1851–1863 (4.4)	
						1917–1942 (12.3)	
4135	6	Below Sz-An	Soil	−22.5	220 ± 90	1530–1935 (1.7)	†
						1635–1707 (29.9)	
						1713–1821 (46.1)	
						1837–1876 (11.5)	
						1914–1942 (10.8)	
3782	9	Below Sz-An	Soil	−17.2	320 ± 70	1496–1604 (74.7)	†
						1614–1650 (25.3)	
4367	5	In Sz-Bm	Charcoal	−24.4	500 ± 70	1320–1341 (11.5)	†
						1392–1479 (88.5)	
4357	11	Below Sz-Bm	Soil	−22.1	670 ± 70	1287–1321 (39.5)	†
						1340–1393 (60.5)	
4136	10	Below Sz-Bm	Soil	−16.8	680 ± 70	1284–1321 (41.9)	†
						1340–1393 (58.1)	
5039	12	Below Sz-Bm	Soil	−22.1	760 ± 80	1192–1306 (94.5)	
						1364–1375 (5.5)	
4073	5	Below Sz-Bm	Soil	−15.2	930 ± 70	1026–1173 (100)	†
4079	8	Below Sz-Tn	Soil	−23.6	1000 ± 80	980–1064 (55.6)	†
						1075–1127 (29.5)	
						1133–1159 (14.9)	
4009	7	Below Sz-Tn	Soil	−27.4	1160 ± 60	819– 846 (18.6)	†
						854– 968 (81.4)	
4148	6	Below Sz-Tn	Soil	−25.0	1210 ± 90	718–741 (10.0)	†
						764–896 (71.7)	
						913–956 (18.4)	
Kaimondake Volcano							
4236	13	Below Km-Nn	Soil	−23.6	1350 ± 100	608–786 (100)	
4141	13	Below Km-Jo	Soil	−17.6	1070 ± 80	881–1039 (100)	

*See Figs. 2, 3 and 4; † = Okuno *et al.* (1997)

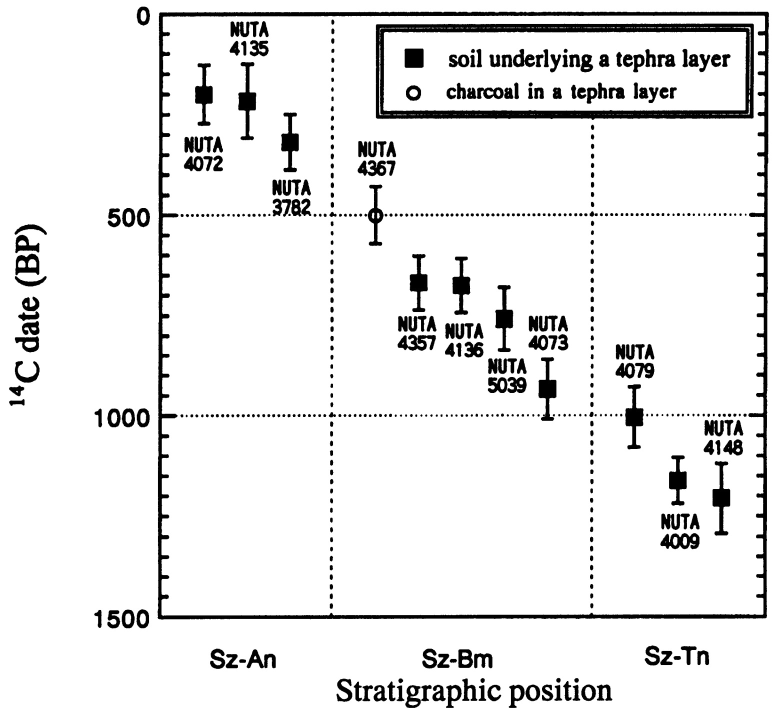

Fig. 6. Relationship between stratigraphic position and AMS ^{14}C date in Sakurajima volcano. Symbols as in Figure 5.

eruption showed a much older range (cal AD 608–786). This time contradiction can be explained by the contamination of the underlying soil material. The tephra layer may destroy vegetation and form rill channels around the volcano. It also causes drainage changes and acceleration of soil erosion. Therefore, we cannot neglect the contamination of the underlying soil in the case of a short repose period preceding an eruption.

Conclusion

From AMS ^{14}C dating of mainly soil samples found just below the tephra layers of historic eruptions of Kirishima, Sakurajima and Kaimondake volcanoes, we conclude:

1. The ^{14}C dates of soil samples are almost consistent with tephra-stratigraphy; however, some calibrated ranges are obviously older than their real calendar age by a few hundred years.
2. The ^{14}C dates of soil materials underlying tephras from eruptions during the historic period can provide parameters useful for correlating tephra layers with documentary records of eruption.
3. In the case of a short repose period preceding an eruption, we cannot neglect the possibility of contamination derived from the underlying soil layer.

Acknowledgments

We acknowledge the helpful collaboration of Prof. H. Moriwaki, Kagoshima University, H. Naruo, Kagoshima Prefectural Museum and M. Tsutsui, DIA Consultants, Japan. This study was funded in part by a Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Science, Sports and Culture (Nos. 9402051 and 9701906).

References

Braitseva, O. A., Sulerzhitsky, L. D., Litasova, S. N. and Melekestsev, I. V. 1993 Radiocarbon dating and tephrochronology in Kamchatka. *Radiocarbon* 35(3): 463–476.

Fujino, N. and Kobayashi, T. 1997 Eruptive history of Kaimondake volcano, southern Kyushu, Japan. *Bulletin of the Volcanological Society of Japan* 42: 195–211 (in Japanese with English abstract).

Fukuyama, H. 1978 Geology of Sakurajima volcano, southern Kyushu. *Journal of the Geological Society of Japan* 84: 309–316 (in Japanese with English abstract).

Imura, R. 1994 Geology of Kirishima volcano. *Bulletin of the Earthquake Research Institute, the University of Tokyo* 69: 189–209 (in Japanese with English abstract).

Imura, R. and Koga, M. 1992 ^{14}C ages of charcoal from the Kirishima volcano and the Ito ignimbrite. *Bulletin of the Volcanological Society of Japan* 37: 99–102 (in Japanese).

Inoue, K. 1988 The growth history of Takachiho composite volcano in the Kirishima volcano group. *Journal of Mineralogy, Petrology and Economic Geology* (Japan) 83: 26–41 (in Japanese with English abstract).

Kitagawa, H., Masuzawa, T., Nakamura, T. and Matsumoto, E. 1993 A batch preparation method for graphite targets with low background for AMS ^{14}C measurements. *Radiocarbon* 35(2): 295–300.

Kobayashi, T. 1982 Geology of Sakurajima volcano: A review. *Bulletin of the Volcanological Society of Japan* 27: 277–292 (in Japanese with English abstract).

Kuwahata, M. and Higashi, K. 1997 Volcanic ash layers and types of pottery in southern Kyushu. *Earth Monthly* 19: 208–214 (in Japanese).

Nakamura, M. 1967 On the volcanic products and history of Kaimon-dake volcano. *Bulletin of the Volcanological Society of Japan* 12: 119–131 (in Japanese with English abstract).

Nakamura, T., Nakai, N. and Ohishi, S. 1987 Applications of environmental ^{14}C measured by AMS as a carbon tracer. *Nuclear Instruments and Methods in Physics Research* B29: 355–360.

Nakamura, T., Nakai, N., Sakase., T., Kimura, M., Ohishi, S., Taniguchi, M. and Yoshioka, S. 1985 Direct detection of radiocarbon using accelerator techniques and its application to age measurement. *Japanese Journal of Applied Physics* 24: 1716–1723.

Naruo, H., Nagayama, S. and Shimoyama, S. 1997 Disasters by the Kofun and Heian eruptions in the Kaimondake volcano: An examination from archaeology and historical documents. *Earth Monthly* 19: 215–222 (in Japanese).

Niklaus T. R., Bonani G., Simonius M., Suter M. and Wölfli, W. 1992 Calib ETH: An interactive computer program for the calibration of radiocarbon dates. *In* Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 483–492.

Okuno, M., Nakamura, T., Moriwaki, H. and Kobayashi, T. 1997 AMS radiocarbon dating of the Sakurajima tephra group, Southern Kyushu, Japan. *Nuclear Instruments and Methods in Physics Research* B123: 470–474.

Orlova, L. A. and Panychev, V. A. 1993 The reliability of radiocarbon dating buried soils. *Radiocarbon* 35(3): 369–377.

Stuiver, M. and Pearson, G. W. 1993 High-precision bidecadal calibration of the radiocarbon time scale, AD 1950–500 BC and 2500–6000 BC. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 1–23.